USE AND LIMIT

OF THE

IMAGINATION IN SCIENCE.

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ESSAYS

ON THE

USE AND LIMIT

OF THE

IMAGINATION IN SCIENCE.

BY

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EXPLANATORY NOTE.

To a Second Edition of a Discourse on the Scientific Use of the Imagination, delivered before the British Association at Liverpool on September 16, 1870, are here added an Address on the Limit of the Imagination in Science, delivered before the Mathematical and Physical Section of the Association at Norwich on August 19, 1868, and a short Essay, entitled 'Earlier Thoughts.'

The Address and the Essay were meant to be brief, but definite statements of the relation of Life and Consciousness to Matter and Force.

As in the case of the recent Discourse, opinion was divided with regard to the objects and merits of the Norwich Address. On the one hand, two eminent clergymen, one of the Church of England, the other a Dissenter, proposed and seconded respectively a vote of thanks, which was liberally carried by the section; on the other hand, I was publicly warned that, as a consequence of my impiety, the bolts of heaven were in a state of potential suspension above my head, ready to descend if further drawn upon.

My main object, both at Norwich and at Liverpool, was, firstly, to dissipate the repugnance, and indeed terror, which in many minds are associated with the thought that science has abolished the mystery of man's relation to the universe; and, secondly, to remove the hindrance which popular notions regarding the origin of life oppose to legitimate scientific speculation.

ATHENÆUM CLUB: *November* 1870.

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PROS AND CONS

TOUCHING THE FIRST EDITION.

From the TIMES, *Sept.* 19, 1870.

THE GLORY of a Natural Philosopher appears to depend less on the power of his imagination to explore minute recesses or immeasurable space than on the skill and patience with which, by observation and experiment, he assures us of the certainty of these invisible operations. Newton's glory is founded, not on the sudden imagination by which he leapt 'from a falling apple to a falling moon,' but on that astonishing tenacity of investigation by which he reduced his guesses to moral certainties, and enabled us to witness a practical verification of his laws in every almanack we use. When the movements of the heavenly bodies have been discovered by this laborious process, the imagination is excellently employed in picturing to the mind's eye what transcends the physical vision; and, perhaps, the labour of the investigation itself would be unendurable unless the attention could be relieved by the constant pictorial aid afforded by the imagination. . . . .

In a word, it seems to us worth consideration whether that use of the imagination in Natural Philosophy of which the Professor speaks needed any encouragement at

the present day. The discoveries of science have been so astonishing, the new worlds they have opened to us are so vast, that there is, perhaps, more danger of our imagination being exercised too freely than of its not being exercised sufficiently upon them. No one will dispute the claim of the Professor to be one of the privileged spirits of whom he speaks, if there are any such, and he proceeds accordingly to exercise his imagination, not upon the little germ-cells, but upon that vast primordial nebulous envelope out of which, according to the opinion to which some philosophers incline, all the infinite complexity of the existing world has been developed. We are not privileged spirits, and we own ourselves not altogether able to follow him when he leads us into the imaginary realms of the original chaos. He confesses that Mr. Darwin 'has drawn heavily upon time and adventurously upon matter.' We ask ourselves again whether we are listening to one experimental philosopher describing the achievements of another experimental philosopher. We had been under the impression that Natural Philosophers drew no bills. We do not presume to say one word about the Evolution Hypothesis. We neither affirm nor deny that Professor Tyndall existed in a nebulous state an infinite number of centuries ago. We only venture to suggest that when the British Association amuse the public with these speculations they are illustrating, not the scientific use of the imagination, but the imaginative use of science.

From the SATURDAY REVIEW, *Sept.* 24, 1870.

Here, too, we question whether Sir William Thomson will be content with this definition of the process by which he has been guided to his most recent advance in molecular physics. In the splendid series of inductions

verified step after step by rigorous experiment and observation, and kept in exactest continuity by the chain of mathematical evolution, is imagination the faculty to which are to be given the chief honours of this conquest of a new realm of physics? This would surely be to force upon us a new and arbitrary classification or analysis of the powers of the intellect. If we follow Professor Tyndall himself through the masterly train of reasoning whereby he leads us to the laws of reflection and transmission of light as the cause of the azure of the firmament, is what we admire the leap of imagination, or the firmly balanced and duly graduated tread of a mind trained in the discipline of logic, and careful to plant every step on the assured ground of fact or experience? It is simply a misnomer to apply the name of imagination to the process or the faculty to which this onward march into the realm of unexplored nature is really due. As well describe as a triumph of the imagination the connected and organized plan of the great strategist which has drawn round Paris a living cordon of 300,000 men.

***From a Lecture addressed to Teachers at the South Kensington Museum, April* 30, 1861, *by* J. TYNDALL.**

Here, then, is an exhibition of power which we can call forth or cause to disappear at pleasure. We magnetize our strip of steel by drawing it along the pole of a magnet; we can demagnetize it, or reverse its magnetism, by properly drawing it along the same pole in the opposite direction. What, then, is the real nature of this wondrous change? What is it that takes place among the atoms of the steel when the substance is magnetized? The question leads us beyond the region of sense, and into that of imagination. This faculty, indeed, is the

divining rod of the man of science. Not, however, an imagination which catches its creations from the air, but one informed and inspired by facts, capable of seizing firmly on a physical image as a principle, of discerning its consequences, and of devising means whereby these forecasts of thought may be brought to an experimental test. If such a principle be adequate to account for all the phenomena, if from an assumed cause the observed facts necessarily follow, we call the assumption a theory, and once possessing it, we can not only revive at pleasure facts already known, but we can predict others which we have never seen. Thus, then, in the prosecution of physical science, our powers of observation, memory, imagination, and inference, are all drawn upon. We observe facts and store them up; imagination broods upon these memories, and by the aid of reason tries to discern their interdependence. The theoretic principle flashes, or slowly dawns upon the mind, and then the deductive faculty interposes to carry out the principle to its logical consequences. A perfect theory gives dominion over natural facts; and even an assumption which can only partially stand the test of a comparison with facts, may be of eminent use in enabling us to connect and classify groups of phenomena.

From the GUARDIAN, *Sept.* 21, 1870.

He held some pieces of paper in his hand, but he rarely referred to them. Thoroughly possessed by his subject, his thoughts seemed to flow forth with perfect ease, fresh minted as they were in the most appropriate and perspicuous words. He led his hearers gently and almost unconsciously through the most perplexed mazes and subtlest passages of thought, keeping their ears en-

chained and their fancy charmed by the endless succession of apt metaphor; and yet, whenever he felt or fancied that their overstrained attention began to flag, he was able to turn aside into light and pleasant banter, and after this interlude of welcome refreshment, to resume again with renewed power the unbroken thread of his serious discourse. It was the manifest work of a master in his art, handling with ease and grace the weighty tools which long use had made familiar to his hand.

From the ENGLISH CHURCHMAN, *Sept.* 29, 1870.

What astonishes us beyond measure is, that a man of Professor Tyndall's real ability and earnestness should sneer at the second verse of the Bible, and speak of it as a legend! Why, surely, he has here the very thing which he is searching—the true origin of life. When chaos ruled over the world, and the earth was void of life; it was the Divine Spirit that breathed over the lifeless mass, and light and life sprang into existence. Without stopping to point out the evidence of the highest Christian doctrine in this passage, we have at least the solution of the enigma of the origin of life, in the revealed truth that it was caused by the Creative Spirit.

From the RECORD, *Sept.* 23, 1870.

Discovery of Motives, No. I.—But why did Professor Tyndall make such an appeal to the imagination of his hearers? His imaginary picture of the occult operations of light was introduced as a plea for the wildness of such weaker brethren, as he calls Mr. Darwin, in speaking of his theory of natural selection, succeeded by his supplementary theory of pangenesis. It is objected to Mr. Darwin's theories by Christian philosophers that these

theories are essentially atheistic. That they are framed for the express purpose of blotting out of the page of nature some of the most marvellous evidences of design—of the most patent revelations of the book of nature, that there is an all-wise, all-mighty Creator, God. That these theories deprive man of all those prerogatives that raise him above the brute. That the facts of nature contradict them. The first theory of Mr. Darwin, that of natural selection, is an attempt to account for the formation of all animal and vegetable beings from an hypothetical germ. . . . Even this does not pall the imagination of Professor Tyndall. He accepts the theory of the avowed atheist Louis Buchner, in his 'Force and Matter,' that the theory of evolution requires us to imagine not only that all the structures, animal and vegetable, were once potentially present in the fire-mist of the nebulous theory, but also that all mental powers—Plato, Shakespeare, Newton, and Raphael—are potential in the fires of the sun.

Professor Tyndall appeals to believers in the Bible as God's Word not to style such a theory wicked or impious. He says men can hold it, and manifest in their lives what he terms so-called Christian virtues. He says, 'They who keep such questions open and will not tolerate any unlawful limitation of the horizon of their souls, have as little fellowship with the atheist who says there is no God, as with the theist who professes to know the mind of God.' These men then are theists, but what kind of a God does their free speculation require? The theists who are sneered at by Professor Tyndall, who believe in a God who has revealed his will and his mind to man, have far higher and more convincing proofs that He has so revealed Himself than Professor Tyndall can ever accumulate for his belief in the undulatory theory of light.

Professor Tyndall's philosophy regards the universe as a huge mechanical, self-supporting, self-sustaining, self-evolving, material machine — untended by a loving Father's sustaining and providential care. His God is the God of the Epicureans, who created and started the machine into motion and then left it for ever to itself. Such a philosophy, the child of unbridled pride of intellect, may appeal to the wildest imagination of corrupted human nature, but it has no sympathy with all the higher yearnings of the soul.

From the LANCET, *Sept.* 24, 1870.

Discovery of Motives, No II.—Now, Professor Tyndall's object was to preach about germs, and he proceeded to accomplish it in somewhat the following manner. He first set forth that it was a wholesome use of the imagination to apply our knowledge of aërial sound-waves to the solution of the question—what is the cause of the phenomena of light? And he then proceeded to draw one of those charming word-pictures for which he is so famous, showing the rippling of the ethereal light-waves against molecules in the atmosphere, the greater proportionate reflection of the shorter wave of blue, and the consequent preponderance of blue rays in the light reflected to us from the sky, and of red and yellow rays in the light coming unreflected from the sun. . . . Now, the aim of all this was to seek and show that the air is filled by an infinite multitude of suspended particles, so minute that they do not produce darkness, and that these particles may be germs. Professor Tyndall does not say that they are germs, but, by the aid of a special disclaimer, he prevented his audience from forgetting that they might be. We should be very loth to

accuse him of disingenuousness, but we are unable entirely to acquit him of special pleading. We feel that his lecture was a very skilful attempt to familiarise the public mind with the existence of atmospheric particles, and to lead up to and encourage, without absolutely expressing the idea that germs are particles, and that particles may be germs.

To the Editor of the RECORD.

SIR,—It is a grave error on your part to represent me as calling Mr. Darwin 'one of the weaker brethren.' Were I asked to name the highest representative of the stronger ones, I should probably name him. But in your article you link my name with that of a writer whom I do rank among the weaker brethren; weak through a defect common to him and his antagonists—the incompetence, namely, to look round a great question and see its bearings on all sides.

I am, Sir, your obedient servant,

JOHN TYNDALL.

ATHENÆUM CLUB, October 4.

From the PALL MALL GAZETTE, *September* 20, 1870.

Why does Professor Tyndall attribute to Goethe the 'notion,' as he calls it, that matter is 'the living garment of God'? We are not aware that it is to be found in his works. In 'Faust' Goethe introduces the spirit of the earth, who describes his own operations as consisting in weaving into one vast fabric the 'tumults of human life, the storm of actions,' births and deaths, and the affairs of us mortals, and working thereout 'a living gar-

ment for the Divinity.' Whether the phrase be a piece of cant, or a piece of sublimity, it has no semblance of the meaning which the Professor attributes to it.

From the SPECTATOR, *September* 24, 1870.

Professor Tyndall concluded his lecture by a passage on the development theory, in which he contended that if our traditional view of matter had been Goethe's view, that matter is 'the living garment of God,' instead of Young's, who looked upon it as foreign to mind, and taking all its laws from outside itself, the development theory would not seem to us what we now mean by materialistic. The 'Pall Mall' falls severely on Professor Tyndall for misquoting Goethe, and shows that the passage in 'Faust' probably referred to, where the Erd-geist speaks of weaving a 'living garment for the Divinity,' did not refer to external nature at all. No doubt the special quotation was a little wide of the mark, but does the critic in the 'Pall Mall' doubt that Professor Tyndall was interpreting quite accurately Goethe's conception, as elsewhere expressed with sufficient elaboration? If he does not, his criticism is a cavil. If he does, let him study Goethe more thoroughly—'Gott und Welt,' for example, of the proem to which a friend has sent us a faithful version to-day, which we print in another column. What can be stronger than this?—

> Was wär' ein Gott der nur von aussen stiesse
> Im Kreis das All am Finger laufen liesse!
> Ihm ziemt's, die Welt im Innern zu bewegen,
> Natur in Sich, Sich in Natur zu hegen.

A Translation of Goethe's Proemium to 'Gott und Welt.'

To Him who from eternity, self-stirred,
Himself hath made by His creative Word!
To him, supreme, who causeth Faith to be,
Trust, Hope, Love, Power, and endless Energy!
To Him, who, seek to name Him as we will,
Unknown within Himself abideth still!

Strain ear and eye, till sight and sense be dim;
Thou'lt find but faint similitudes of Him:
Yea, and thy spirit in her flight of flame
Still strives to gauge the symbol and the name:
Charmed and compelled thou climb'st from height to height,
And round thy path the world shines wondrous bright;
Time, Space, and Size, and Distance cease to be,
And every step is fresh infinity.

What were the God who sat outside to scan
The spheres that 'neath his finger circling ran?
God dwells within, and moves the world and moulds,
Himself and Nature in one form enfolds:
Thus all that lives in Him and breathes and is,
Shall ne'er His puissance, ne'er His spirit miss.

The soul of man, too, is an universe:
Whence follows it that race with race concurs
In naming all it knows of good and true
God,—yea, its own God; and with homage due
Surrenders to His sway both earth and heaven;
Fears Him, and loves, where place for love is given.

J. A. S.

From the SPECTATOR, September 24.

From the TIMES, *October* 3, 1870.

But the most serious obstacle of a public nature which can possibly impede the progress of science—an obstacle before which all others sink into absolute insignificance—is *the reign of prejudice*, or the unwillingness to adopt the teachings of science, and to accept her legitimate conclusions through certain preconceived opinions, the result of a faulty education or a vicious temperament. To this, indeed, we think the British Association cannot pay too much attention, and we were not a little gratified, in consequence, at the eloquent lecture on the use of the imagination in science delivered by Professor Tyndall. The importance of such a discourse at such a time to clear the atmosphere of the clouds of prejudice which a mistaken zeal has raised in the minds of a large class cannot be over-estimated. Since it is certain that religious intolerance and religious bigotry are the largest sources of prejudice, the removal of these ought to be a primary object of the association, and when the undertaking is made with the same spirit of reverence, the same earnestness of purpose, and philosophical acumen which distinguished Professor Tyndall's discourse, it seems impossible to doubt that much benefit must ultimately result thereby to the cause of truth. The impression produced on our minds by that philosophical masterpiece will not be easily effaced. As we listened in that crowded hall with admiration to the thoughtful investigator who was unfolding to us the workings of a mind much more than ordinarily acute, we pictured to ourselves the effect which it was so well calculated to produce in the mind of the sceptic in science. We saw in imagination the victory of conscience and reason, the emancipation of a soul, the new birth of an

intelligence. As the speaker welded one link to another of the long chain of ratiocination, his ardour rising with the progress of his argument, we thought that it had never been our good fortune to listen to so splendid a discourse. But the end was not yet. The grand appeal had still to be made. In a magnificent peroration Professor Tyndall concluded an argument of no common order—an argument not fitted, indeed, to assuage the terrors of a vicious imagination; an argument which may perchance have grated harshly on the sacerdotal ear; but an argument which elicited thunders of applause from an audience more than usually critical—with an appeal of unrivalled eloquence to abandon dogmatism for ever, and fairly bring every hypothesis before the bar of a disciplined reason. The place and the people were worthy of the man. In a vast hall whose name recalls the finest relics of the old English ballad were gathered together all that the most populous and intelligent shire of Britain could produce of talent and influence, while grouped around the presidential chair were many of the most brilliant ornaments of British science and the representatives of foreign philosophy. It may, indeed, be surmised that of the three thousand souls who listened to Professor Tyndall's lay sermon there were few who entered into the discussion prepared to embrace his views. Yet we think that there were few also who left that hall at all events without a doubt that the search after truth which is the sole object of the investigation of nature is neither so prosaic nor so dangerous a quest as the false prophets and the Philistines would assert—that philosophy is not 'harsh and crabbed as dull fools suppose'—

> But musical as is Apollo's lute.
> And a perpetual feast of nectar'd sweets,
> Where no crude surfeit reigns.

SCIENTIFIC USE OF THE IMAGINATION.

I CARRIED with me to the Alps this year the heavy burden of this evening's work. In the way of new investigation I had nothing complete enough to be brought before you; so all that remained to me was to fall back upon such residues as I could find in the depths of consciousness, and out of them to spin the fibre and weave the web of this discourse. Save from memory I had no direct aid upon the mountains; but to spur up the emotions, on which so much depends, as well as to nourish indirectly the intellect and will, I took with me two volumes of poetry, Goethe's 'Farbenlehre,' and the work on 'Logic' recently published by Mr. Alexander Bain.* The spur, I am sorry to say, was no match for the integument of dulness it had to pierce. In Goethe, so glorious otherwise, I chiefly noticed the self-inflicted hurts of genius, as it broke itself in vain against the philosophy of Newton. For a time, Mr. Bain became my principal companion. I found him learned and practical, shining generally with a dry light, but exhibiting at times a flush of emotional strength, which proved that even logicians share the common fire of

* One of my critics remarks, that he does not see the wit of calling Goethe's 'Farbenlehre' and Bain's 'Logic,' 'two volumes of poetry.' Nor do I.

humanity. He interested me most when he became the mirror of my own condition. Neither intellectually nor socially is it good for man to be alone, and the griefs of thought are more patiently borne when we find that they have been experienced by another. From certain passages in his book I could infer that Mr. Bain was no stranger to such sorrows. Take this passage as an illustration. Speaking of the ebb of intellectual force, which we all from time to time experience, Mr. Bain says, 'The uncertainty where to look for the next opening of discovery brings the pain of conflict and the debility of indecision.' These words have in them the true ring of personal experience. The action of the investigator is periodic. He grapples with a subject of enquiry, wrestles with it, overcomes it, exhausts, it may be, both himself and it for the time being. He breathes a space, and then renews the struggle in another field. Now this period of halting between two investigations is not always one of pure repose. It is often a period of doubt and discomfort, of gloom and ennui. 'The uncertainty where to look for the next opening of discovery brings the pain of conflict and the debility of indecision.' Such was my precise condition in the Alps this year; in a score of words Mr. Bain has here sketched my mental diagnosis; and it was under these evil circumstances that I had to equip myself for the hour and the ordeal that are now come.

Gladly, however, as I should have seen this duty in other hands, I could by no means shrink from it. Disloyalty would have been worse than failure. In some fashion or other—feebly or strongly, meanly or manfully, on the higher levels of thought, or on the flats of common-place,—the task had to be accomplished. I looked in various directions for help and furtherance; but without me for a time I saw only 'antres vast,'

and within me 'deserts idle.' My case resembled that of a sick doctor who had forgotten his art and sorely needed the prescription of a friend. Mr. Bain wrote one for me. He said, 'Your present knowledge must forge the links of connection between what has been already achieved and what is now required.' * In these words he admonished me to review the past and recover from it the broken ends of former investigations. I tried to do so. Previous to going to Switzerland I had been thinking much of light and heat, of magnetism and electricity, of organic germs, atoms, molecules, spontaneous generation, comets, and skies. With one or another of these I now sought to re-form an alliance, and finally succeeded in establishing a kind of cohesion between thought and Light. The wish grew within me to trace, and to enable you to trace, some of the more occult operations of this agent. I wished, if possible, to take you behind the drop-scene of the senses, and to show you the hidden mechanism of optical action. For I take it to be well worth the while of the scientific teacher to take some pains, and even great pains, to make those whom he addresses copartners of his thoughts. To clear his own mind in the first place from all haze and vagueness, and then to project into language which shall leave no mistake as to his meaning—which shall leave even his errors naked—the definite ideas he has shaped. A great deal is, I think, possible to scientific exposition conducted in this way. It is possible, I believe, even before an audience like the present, to uncover to some extent the unseen things of nature; and thus to give, not only to professed students, but to others with the necessary bias, industry, and capacity, an intelligent

interest in the operations of science. Time and labour are necessary to this result, but science is the gainer from the public sympathy thus created.

How then are those hidden things to be revealed? How, for example, are we to lay hold of the physical basis of light, since, like that of life itself, it lies entirely without the domain of the senses? Now philosophers may be right in affirming that we cannot transcend experience. But we can, at all events, carry it a long way from its origin. We can also magnify, diminish, qualify, and combine experiences, so as to render them fit for purposes entirely new. We are gifted with the power of Imagination,—combining what the Germans call Anschauungsgabe and Einbildungskraft—and by this power we can lighten the darkness which surrounds the world of the senses. There are tories even in science who regard imagination as a faculty to be feared and avoided rather than employed. They had observed its action in weak vessels and were unduly impressed by its disasters. But they might with equal justice point to exploded boilers as an argument against the use of steam. Bounded and conditioned by cooperant Reason, imagination becomes the mightiest instrument of the physical discoverer. Newton's passage from a falling apple to a falling moon was, at the outset, a leap of the imagination. When William Thomson tries to place the ultimate particles of matter between his compass points, and to apply to them a scale of millimetres, he is powerfully aided by this faculty. And in much that has been recently said about protoplasm and life, we have the outgoings of the imagination guided and controlled by the known analogies of science. In fact, without this power, our knowledge of nature would be a mere tabulation of coexistences and sequences. We should still believe in the succession of day and night, of summer

and winter; but the soul of Force would be dislodged from our universe; causal relations would disappear, and with them that science which is now binding the parts of nature to an organic whole.

I should like to illustrate by a few simple instances the use that scientific men have already made of this power of imagination, and to indicate afterwards some of the further uses that they are likely to make of it. Let us begin with the rudimentary experiences. Observe the falling of heavy rain-drops into a tranquil pond. Each drop as it strikes the water becomes a centre of disturbance, from which a series of ring-ripples expand outwards. Gravity and inertia are the agents by which this wave-motion is produced, and a rough experiment will suffice to show that the rate of propagation does not amount to a foot a second. A series of slight mechanical shocks is experienced by a body plunged in the water as the wavelets reach it in succession. But a finer motion is at the same time set up and propagated. If the head and ears be immersed in the water, as in an experiment of Franklin's, the shock of the drop is communicated to the auditory nerve—the *tick* of the drop is heard. Now this sonorous impulse is propagated, not at the rate of a foot a second, but at the rate of 4,700 feet a second. In this case it is not the gravity, but the *elasticity* of the water that is the urging force. Every liquid particle pushed against its neighbour delivers up its motion with extreme rapidity, and the pulse is propagated as a thrill. The incompressibility of water, as illustrated by the famous Florentine experiment, is a measure of its elasticity, and to the possession of this property in so high a degree the rapid transmission of a sound-pulse through water is to be ascribed.

But water, as you know, is not necessary to the conduction of sound; air is its most common vehicle. And

you know that when the air possesses the particular density and elasticity corresponding to the temperature of freezing water the velocity of sound in it is 1,090 feet a second. It is almost exactly one-fourth of the velocity in water; the reason being that though the greater weight of the water tends to diminish the velocity, the enormous molecular elasticity of the liquid far more than atones for the disadvantage due to weight. By various contrivances we can compel the vibrations of the air to declare themselves; we know the length and frequency of sonorous waves, and we have also obtained great mastery over the various methods by which the air is thrown into vibration. We know the phenomena and laws of vibrating rods, of organ-pipes, strings, membranes, plates, and bells. We can abolish one sound by another. We know the physical meaning of music and noise, of harmony and discord. In short, as regards sound we have a very clear notion of the external physical processes which correspond to our sensations.

In these phenomena of sound we travel a very little way from downright sensible experience. Still the imagination is to some extent exercised. The bodily eye, for example, cannot see the condensations and rarefactions of the waves of sound. We construct them in thought, and we believe as firmly in their existence as in that of the air itself. But now our experience has to be carried into a new region, where a new use is to be made of it. Having mastered the cause and mechanism of sound, we desire to know the cause and mechanism of light. We wish to extend our enquiries from the auditory nerve to the optic nerve. Now there is in the human intellect a power of expansion—I might almost call it a power of creation—which is brought into play by the simple brooding upon facts. The legend of the Spirit brooding

over chaos may have originated in a knowledge of this power. In the case now before us it has manifested itself by transplanting into space, for the purposes of light, an adequately modified form of the mechanism of sound. We know intimately whereon the velocity of sound depends. When we lessen the density of a medium and preserve its elasticity constant we augment the velocity. When we heighten the elasticity and keep the density constant we also augment the velocity. A small density, therefore, and a great elasticity, are the two things necessary to rapid propagation. Now light is known to move with the astounding velocity of 185,000 miles a second. How is such a velocity to be obtained? By boldly diffusing in space a medium of the requisite tenuity and elasticity. Let us make such a medium our starting point, endowing it with one or two other necessary qualities; let us handle it in accordance with strict mechanical laws; give to every step of our deduction the surety of the syllogism; carry it thus forth from the world of imagination to the world of sense, and see whether the final outcrop of the deduction be not the very phenomena of light which ordinary knowledge and skilled experiment reveal. If in all the multiplied varieties of these phenomena, including those of the most remote and entangled description, this fundamental conception always brings us face to face with the truth; if no contradiction to our deductions from it be found in external nature, but on all sides agreement and verification; if, moreover, as in the case of Conical Refraction and in other cases, it has actually forced upon our attention phenomena which no eye had previously seen, and which no mind had previously imagined, such a conception, which never disappoints us, but always lands us on the solid shores of fact, must, we think, be something more than a mere

figment of the scientific fancy. In forming it that composite and creative unity in which reason and imagination are together blent, has, we believe, led us into a world not less real than that of the senses, and of which the world of sense itself is the suggestion and justification.

Far be it from me, however, to wish to fix you immovably in this or in any other theoretic conception. With all our belief of it, it will be well to keep the theory plastic and capable of change. You may, moreover, urge that although the phenomena occur *as if* the medium existed, the absolute demonstration of its existence is still wanting. Far be it from me to deny to this reasoning such validity as it may fairly claim. Let us endeavour by means of analogy to form a fair estimate of its force. You believe that in society you are surrounded by reasonable beings like yourself. You are perhaps as firmly convinced of this as of anything. What is your warrant for this conviction? Simply and solely this, your fellow-creatures behave as if they were reasonable; the hypothesis, for it is nothing more, accounts for the facts. To take an eminent example: you believe that our President is a reasonable being. Why? There is no known method of superposition by which any one of us can apply himself intellectually to another so as to demonstrate coincidence as regards the possession of reason. If, therefore, you hold our President to be reasonable, it is because he behaves *as if* he were reasonable. As in the case of the ether, beyond the '*as if*' you cannot go. Nay I should not wonder if a close comparison of the data on which both inferences rest, caused many respectable persons to conclude that the ether had the best of it.

This universal medium, this light-ether as it is called, is a vehicle, not an origin of wave-motion. It receives and transmits, but it does not create. Whence does it derive

the motions it conveys? For the most part from luminous bodies. By this motion of a luminous body I do not mean its sensible motion, such as the flicker of a candle, or the shooting out of red prominences from the limb of the sun. I mean an intestine motion of the atoms or molecules of the luminous body. But here a certain reserve is necessary. Many chemists of the present day refuse to speak of atoms and molecules as real things. Their caution leads them to stop short of the clear, sharp, mechanically intelligible atomic theory enunciated by Dalton, or any form of that theory, and to make the doctrine of multiple proportions their intellectual bourne. I respect the caution, though I think it is here misplaced. The chemists who recoil from these notions of atoms and molecules accept without hesitation the Undulatory Theory of Light. Like you and me they one and all believe in an ether and its light producing waves. Let us consider what this belief involves. Bring your imaginations once more into play and figure a series of sound-waves passing through air. Follow them up to their origin, and what do you there find? A definite, tangible, vibrating body. It may be the vocal chords of a human being, it may be an organ-pipe, or it may be a stretched string. Follow in the same manner a train of ether waves to their source; remembering at the same time that your ether is matter, dense, elastic, and capable of motions subject to and determined by mechanical laws. What then do you expect to find as the source of a series of ether waves? Ask your imagination if it will accept a vibrating multiple proportion—a numerical ratio in a state of oscillation? I do not think it will. You cannot crown the edifice by this abstraction. The scientific imagination, which is here authoritative, demands as the origin and cause of a series of ether waves a particle of vibrating

matter quite as definite, though it may be excessively minute, as that which gives origin to a musical sound. Such a particle we name an atom or a molecule. I think the seeking intellect when focussed so as to give definition without penumbral haze, is sure to realise this image at the last.

To preserve thought continuous throughout this discourse, to prevent either lack of knowledge or failure of memory from producing any rent in our picture, I here propose to run rapidly over a bit of ground which is probably familiar to most of you, but which I am anxious to make familiar to you all. The waves generated in the ether by the swinging atoms of luminous bodies are of different lengths and amplitudes. The amplitude is the width of swing of the individual particles of the wave. In water-waves it is the height of the crest above the trough, while the length of the wave is the distance between two consecutive crests. The aggregate of waves emitted by the sun may be broadly divided into two classes: the one class competent, the other incompetent, to excite vision. But the light-producing waves differ markedly among themselves in size, form, and force. The length of the largest of these waves is about twice that of the smallest, but the amplitude of the largest is probably a hundred times that of the smallest. Now the force or energy of the wave, which, expressed with reference to sensation, means the intensity of the light, is proportional to the square of the amplitude. Hence the amplitude being one-hundredfold, the energy of the largest light-giving waves would be ten-thousandfold that of the smallest. This is not improbable. I use these figures not with a view to numerical accuracy, but to give you definite ideas of the differences that probably exist among the light-giving waves. And if we take the

whole range of solar radiation into account—its non-visual as well as its visual waves—I think it probable that the force or energy of the largest wave is a million times that of the smallest.

Turned into their equivalents of sensation, the different light-waves produce different colours. Red, for example, is produced by the largest waves, violet by the smallest, while green is produced by a wave of intermediate length and amplitude. On entering from air into more highly refracting substances, such as glass or water, or the sulphide of carbon, all the waves are retarded, but the smallest ones most. This furnishes a means of separating the different classes of waves from each other; in other words, of analysing the light. Sent through a refracting prism, the waves of the sun are turned aside in different degrees from their direct course, the red least, the violet most. They are virtually pulled asunder, and they paint upon a white screen placed to receive them 'the solar spectrum.' Strictly speaking, the spectrum embraces an infinity of colours, but the limits of language and of our powers of distinction cause it to be divided into seven segments: red, orange, yellow, green, blue, indigo, violet. These are the seven primary or prismatic colours. Separately, or mixed in various proportions, the solar waves yield all the colours observed in nature and employed in art. Collectively, they give us the impression of whiteness. Pure unsifted solar light is white; and if all the wave-constituents of such light be reduced in the same proportion, the light, though diminished in intensity, will still be white. The whiteness of Alpine snow with the sun shining upon it, is barely tolerable to the eye. The same snow under an overcast firmament is still white. Such a firmament enfeebles the light by reflection, and

when we lift ourselves above a cloud-field—to an Alpine summit, for instance, or to the top of Snowdon—and see, in the proper direction, the sun shining on the clouds, they appear dazzlingly white. Ordinary clouds, in fact, divide the solar light impinging on them into two parts—a reflected part and a transmitted part, in each of which the proportions of wave-motion which produce the impression of whiteness are sensibly preserved.

It will be understood that the conditions of whiteness would fail if all the waves were diminished *equally*, or by the same absolute quantity. They must be reduced *proportionately*, instead of equally. If by the act of reflexion the waves of red light are split into exact halves, then, to preserve the light white, the waves of yellow, orange, green, and blue must also be split into exact halves. In short, the reduction must take place, not by absolutely equal quantities, but by equal fractional parts. In white light the preponderance as regards energy of the larger over the smaller waves must always be immense. Were the case otherwise, the physiological correlative, *blue*, of the smaller waves would have the upper hand in our sensations.

My wish to render our mental images complete, causes me to dwell briefly upon these known points, and the same wish will cause me to linger a little longer among others. But here I am disturbed by my reflections. When I consider the effect of dinner upon the nervous system, and the relation of that system to the intellectual powers I am now invoking—when I remember that the universal experience of mankind has fixed upon certain definite elements of perfection in an after-dinner speech, and when I think how conspicuous by their absence these elements are on the present occasion, the thought is not comforting to a man who wishes to stand well with his

fellow-creatures in general, and with the members of the British Association in particular. My condition might well resemble that of the ether, which is scientifically defined as an assemblage of vibrations. And the worst of it is that unless you reverse the general verdict regarding the effect of dinner, and prove in your own persons that a uniform experience need not continue uniform—which will be a great point gained for some people—these tremors of mine are likely to become more and more painful. But I call to mind the comforting words of an inspired though uncanonical writer, who admonishes us in the Apocrypha that fear is a bad counsellor. Let me then cast him out, and let me trustfully assume that you will one and all postpone that balmy sleep, of which dinner might under the circumstances be regarded as the indissoluble antecedent, and that you will manfully and womanfully prolong your investigations of the ether and its waves into regions which have been hitherto crossed by the pioneers of science alone.

Not only are the waves of ether reflected by clouds, by solids, and by liquids, but when they pass from light air to dense, or from dense air to light, a portion of the wave-motion is always reflected. Now our atmosphere changes continually in density from top to bottom. It will help our conceptions if we regard it as made up of a series of thin concentric layers, or shells of air, each shell being of the same density throughout, and a small and sudden change of density occurring in passing from shell to shell. Light would be reflected at the limiting surfaces of all these shells, and their action would be practically the same as that of the real atmosphere. And now I would ask your imagination to picture this act of reflection. What must become of the reflected light? The atmospheric layers turn their convex surfaces towards the sun, they are

so many convex mirrors of feeble power, and you will immediately perceive that the light regularly reflected from these surfaces cannot reach the earth at all, but is dispersed in space.

But though the sun's light is not reflected in this fashion from the aërial layers to the earth, there is indubitable evidence to show that the light of our firmament is reflected light. Proofs of the most cogent description could be here adduced; but we need only consider that we receive light at the same time from all parts of the hemisphere of heaven. The light of the firmament comes to us across the direction of the solar rays, and even against the direction of the solar rays; and this lateral and opposing rush of wave-motion can only be due to the rebound of the waves from the air itself, or from something suspended in the air. It is also evident that, unlike the action of clouds, the solar light is not reflected by the sky in the proportions which produce white. The sky is blue, which indicates a deficiency on the part of the larger waves. In accounting for the colour of the sky, the first question suggested by analogy would undoubtedly be, is not the air blue? The blueness of the air has in fact been given as a solution of the blueness of the sky. But reason basing itself on observation, asks in reply, How, if the air be blue, can the light of sunrise and sunset, which travels through vast distances of air, be yellow, orange, or even red? The passage of the white solar light through a blue medium could by no possibility redden the light. The hypothesis of a blue air is therefore untenable. In fact the agent, whatever it is, which sends us the light of the sky, exercises in so doing a dichroitic action. The light reflected is blue, the light transmitted is orange or red. A marked distinction is thus exhibited between the matter of the

sky and that of an ordinary cloud, which latter exercises no such dichroitic action.

By the force of imagination and reason combined we may penetrate this mystery also. The cloud takes no note of size on the part of the waves of ether, but reflects them all alike. It exercises no selective action. Now the cause of this may be that the cloud particles are so large in comparison with the size of the waves of ether as to reflect them all indifferently. A broad cliff reflects an Atlantic roller as easily as a ripple produced by a sea-bird's wing; and in the presence of large reflecting surfaces, the existing differences of magnitude among the waves of ether may disappear. But supposing the reflecting particles, instead of being very large, to be very small, in comparison with the size of the waves. In this case, instead of the whole wave being fronted and in great part thrown back, a small portion only is shivered off. The great mass of the wave passes over such a particle without reflection. Scatter then a handful of such minute foreign particles in our atmosphere, and set imagination to watch their action upon the solar waves. Waves of all sizes impinge upon the particles, and you see at every collision a portion of the impinging wave struck off by reflection. All the waves of the spectrum, from the extreme red to the extreme violet, are thus acted upon. But in what proportions will the waves be scattered? A clear picture will enable us to anticipate the experimental answer. Remembering that the red waves are to the blue much in the relation of billows to ripples, let us consider whether those extremely small particles are competent to scatter all the waves in the same proportion. If they be not—and a little reflection will make it clear to you that they are not—the production of colour must be an incident of the scattering. Largeness is a thing of

relation; and the smaller the wave, the greater is the relative size of any particle on which the wave impinges, and the greater also the ratio of the reflected portion to the total wave. A pebble placed in the way of the ring-ripples produced by our heavy rain-drops on a tranquil pond will throw back a large fraction of the ripple incident upon it, while the fractional part of a larger wave thrown back by the same pebble might be infinitesimal. Now we have already made it clear to our minds that to preserve the solar light white, its constituent proportions must not be altered; but in the act of division performed by these very small particles we see that the proportions *are* altered; an undue fraction of the smaller waves is scattered by the particles, and, as a consequence, in the scattered light, blue will be the predominant colour. The other colours of the spectrum must, to some extent, be associated with the blue. They are not absent but deficient. We ought, in fact, to have them all, but in diminishing proportions, from the violet to the red.

We have here presented a case to the imagination, and, assuming the undulatory theory to be a reality, we have, I think, fairly reasoned our way to the conclusion, that were particles, small in comparison to the size of the ether waves, sown in our atmosphere, the light scattered by those particles would be exactly such as we observe in our azure skies. When this light is analysed, all the colours of the spectrum are found; but they are found in the proportions indicated by our conclusion.

Let us now turn our attention to the light which passes unscattered among the particles. How must it be finally affected? By its successive collisions with the particles the white light is more and more robbed of its shorter waves; it therefore loses more and more of its due pro-

portion of blue. The result may be anticipated. The transmitted light, where short distances are involved, will appear yellowish. But as the sun sinks towards the horizon the atmospheric distances increase, and consequently the number of the scattering particles. They abstract in succession the violet, the indigo, the blue, and even disturb the proportions of green. The transmitted light under such circumstances must pass from yellow through orange to red. This also is exactly what we find in nature. Thus, while the reflected light gives us at noon the deep azure of the Alpine skies, the transmitted light gives us at sunset the warm crimson of the Alpine snows. The phenomena certainly occur *as if* our atmosphere were a medium rendered slightly turbid by the mechanical suspension of exceedingly small foreign particles.

Here, as before, we encounter our sceptical '*as if*.' It is one of the parasites of science, ever at hand, and ready to plant itself and sprout, if it can, on the weak points of our philosophy. But a strong constitution defies the parasite, and in our case, as we question the phenomena, probability grows like growing health, until in the end the malady of doubt is completely extirpated. The first question that naturally arises is—Can small particles be really proved to act in the manner indicated? No doubt of it. Each one of you can submit the question to an experimental test. Water will not dissolve resin, but spirit will; and when spirit which holds resin in solution is dropped into water, the resin immediately separates in solid particles, which render the water milky. The coarseness of this precipitate depends on the quantity of the dissolved resin. You can cause it to separate in thick clots or in exceedingly fine particles. Professor Brücke has given us the proportions which produce particles particularly suited to our present purpose. One gramme of clean

mastic is dissolved in eighty-seven grammes of absolute alcohol, and the transparent solution is allowed to drop into a beaker containing clear water kept briskly stirred. An exceedingly fine precipitate is thus formed, which declares its presence by its action upon light. Placing a dark surface behind the beaker, and permitting the light to fall into it from the top or front, the medium is seen to be distinctly blue. It is not perhaps so perfect a blue as I have seen on exceptional days, this year, among the Alps, but it is a very fair sky-blue. A trace of soap in water gives a tint of blue. London, and I fear Liverpool milk, makes an approximation to the same colour through the operation of the same cause; and Helmholtz has irreverently disclosed the fact that a blue eye is simply a turbid medium.

The action of turbid media upon light was illustrated by Goethe, who, though unacquainted with the undulatory theory, was led by his experiments to regard the firmament as an illuminated turbid medium with the darkness of space behind it. He describes glasses showing a bright yellow by transmitted, and a beautiful blue by reflected light. Professor Stokes, who was probably the first to discern the real nature of the action of small particles on the waves of ether, describes a glass of a similar kind.* Capital specimens of such glass are to be found at Salviati's in St. James's Street. What artists call 'chill' is no doubt an effect of this description. Through the action of minute particles, the browns of a picture

* This glass, by reflected light, had a colour 'strongly resembling that of a decoction of horse-chestnut bark.' Curiously enough Goethe refers to this very decoction:—'Man nehme einen Streifen frischer Rinde von der Rosskastanie, man stecke denselben in ein Glas Wasser, und in der kürzesten Zeit werden wir das vollkommenste Himmelblau entstehen sehen.'—Goethe's *Werke*, b. xxix. p. 24.

often present the appearance of the bloom of a plum. By rubbing the varnish with a silk handkerchief optical continuity is established, and the chill disappears. Some years ago I witnessed Mr. Hirst experimenting at Zermatt on the turbid water of the Visp, which was charged with the finely divided matter ground down by the glaciers. When kept still for a day or so, the grosser matter sank, but the finer matter remained suspended, and gave a distinctly blue tinge to the water. The blueness of certain Alpine lakes has been shown to be in part due to this cause. Prof. Roscoe has noticed several striking cases of a similar kind. In a very remarkable paper the late Principal Forbes showed that steam issuing from the safety-valve of a locomotive, when favourably observed, exhibits at a certain stage of its condensation the colours of the sky. It is blue by reflected light, and orange or red by transmitted light. The effect, as pointed out by Goethe, is to some extent exhibited by peat smoke. More than ten years ago I amused myself at Killarney by observing on a calm day the straight smoke-columns rising from the chimneys of the cabins. It was easy to project the lower portion of a column against a dark pine, and its upper portion against a bright cloud. The smoke in the former case was blue, being seen mainly by reflected light; in the latter case it was reddish, being seen mainly by transmitted light. Such smoke was not in exactly the condition to give us the glow of the Alps, but it was a step in this direction. Brücke's fine precipitate above referred to looks yellowish by transmitted light, but by duly strengthening the precipitate you may render the white light of noon as ruby-coloured as the sun when seen through Liverpool smoke, or upon Alpine horizons. I do not, however, point to the gross smoke arising from coal as an illustration of the action of small particles,

because such smoke soon absorbs and destroys the waves of blue instead of sending them to the eyes of the observer.

These multifarious facts, and numberless others which cannot now be referred to, are explained by reference to the single principle, that where the scattering particles are small in comparison to the size of the waves we have in the reflected light a greater proportion of the smaller waves, and in the transmitted light a greater proportion of the larger waves, than existed in the original white light. The physiological consequence is that in the one light blue is predominant, and in the other light orange or red. And now let us push our enquiries forward. Our best microscopes can readily reveal objects not more than $\frac{1}{50000}$th of an inch in diameter. This is less than the length of a wave of red light. Indeed a first-rate microscope would enable us to discern objects not exceeding in diameter the length of the smallest waves of the visible spectrum. By the microscope therefore we can submit our particles to an experimental test. If they are as large as the light-waves they will infallibly be seen; and if they are not seen it is because they are smaller. I placed in the hands of our President a bottle containing Brücke's particles in greater number and coarseness than those examined by Brücke himself. The liquid was a milky blue, and Mr. Huxley applied to it his highest microscopic power. He satisfied me at the time that had particles of even $\frac{1}{100000}$th of an inch in diameter existed in the liquid they could not have escaped detection. But no particles were seen. Under the microscope the turbid liquid was not to be distinguished from distilled water. Brücke, I may say, also found the particles to be of ultra-microscopic magnitude.

But we have it in our power to imitate far more closely

than we have hitherto done the natural conditions of this problem. We can generate in air, as many of you know, artificial skies, and prove their perfect identity with the natural one, as regards the exhibition of a number of wholly unexpected phenomena. By a continuous process of growth moreover we are able to connect sky-matter, if I may use the term, with molecular matter on the one side, and with molar matter, or matter in sensible masses, on the other. In illustration of this, I will take an experiment described by M. Morren of Marseilles at the last meeting of the British Association. Sulphur and oxygen combine to form sulphurous acid gas. It is this choking gas that is smelt when a sulphur match is burnt in air. Two atoms of oxygen and one of sulphur constitute the molecule of sulphurous acid. Now it has been recently shown in a great number of instances that waves of ether issuing from a strong source, such as the sun or the electric light, are competent to shake asunder the atoms of gaseous molecules. A chemist would call this 'decomposition' by light; but it behoves us, who are examining the power and function of the imagination, to keep constantly before us the physical images which we hold to underlie our terms. Therefore I say, sharply and definitely, that the components of the molecules of sulphurous acid are shaken asunder by the ether waves. Enclosing the substance in a suitable vessel, placing it in a dark room, and sending through it a powerful beam of light, we at first see nothing: the vessel containing the gas is as empty as a vacuum. Soon, however, along the track of the beam a beautiful sky-blue colour is observed, which is due to the liberated particles of sulphur. For a time the blue grows more intense; it then becomes whitish; and from a whitish blue it passes to a more or less perfect white. If the action be continued long enough, we end by filling the tube with a

dense cloud of sulphur particles, which by the application of proper means may be rendered visible.

Here then our ether waves untie the bond of chemical affinity, and liberate a body—sulphur—which at ordinary temperatures is a solid, and which therefore soon becomes an object of the senses. We have first of all the free atoms of sulphur, which are both invisible and incompetent to stir the retina sensibly with scattered light. But these atoms gradually coalesce and form particles, which grow larger by continual accretion until after a minute or two they appear as sky-matter. In this condition they are invisible themselves, but competent to send an amount of wave-motion to the retina sufficient to produce the firmamental blue. The particles continue, or may be caused to continue, in this condition for a considerable time, during which no microscope can cope with them. But they continually grow larger, and pass by insensible gradations into the state of *cloud*, when they can no longer elude the armed eye. Thus without solution of continuity we start with matter in the molecule, and end with matter in the mass, sky-matter being the middle term of the series of transformations.

Instead of sulphurous acid, we might choose from a dozen other substances, and produce the same effect with any of them. In the case of some—probably in the case of all—it is possible to preserve matter in the skyey condition for fifteen or twenty minutes under the continual operation of the light. During these fifteen or twenty minutes the particles are constantly growing larger, without ever exceeding the size requisite to the production of the celestial blue. Now when two vessels are placed before you, each containing sky-matter, it is possible to state with great distinctness which vessel contains the largest particles. The retina is very sensitive to differences

of light, when, as here, the eye is in comparative darkness, and when the quantities of wave-motion thrown against the retina are small. The larger particles declare themselves by the greater whiteness of their scattered light. Call now to mind the observation, or effort at observation, made by our President, when he failed to distinguish the particles of mastic in Brücke's medium, and when you have done so follow me. I permitted a beam of light to act upon a certain vapour. In two minutes the azure appeared, but at the end of fifteen minutes it had not ceased to be azure. After fifteen minutes, for example, its colour, and some other phenomena, pronounced it to be a blue of distinctly smaller particles than those sought for in vain by Mr. Huxley. These particles, as already stated, must have been less than $\frac{1}{100000}$th of an inch in diameter. And now I want you to submit to your imagination the following question: Here are particles which have been growing continually for fifteen minutes, and at the end of that time are demonstrably smaller than those which defied the microscope of Mr. Huxley:—*what must have been the size of these particles at the beginning of their growth?* What notion can you form of the magnitude of such particles? The distances of stellar space give us simply a bewildering sense of vastness without leaving any distinct impression on the mind, and the magnitudes with which we have here to do bewilder us equally in the opposite direction. We are dealing with infinitesimals compared with which the test objects of the microscope are literally immense.

From their perviousness to stellar light, and other considerations, Sir John Herschel drew some startling conclusions regarding the density and weight of comets. You know that these extraordinary and mysterious bodies sometimes throw out tails 100,000,000 of miles in length, and

50,000 miles in diameter. The diameter of our earth is 8,000 miles. Both it and the sky, and a good portion of space beyond the sky, would certainly be included in a sphere 10,000 miles across. Let us fill this sphere with cometary matter, and make it our unit of measure. An easy calculation informs us that to produce a comet's tail of the size just mentioned about 300,000 such measures would have to be emptied into space. Now suppose the whole of this stuff to be swept together, and suitably compressed, what do you suppose its volume would be? Sir John Herschel would probably tell you that the whole mass might be carted away at a single effort by one of your dray-horses. In fact, I do not know that he would require more than a small fraction of a horse-power to remove the cometary dust. After this you will hardly regard as monstrous a notion I have sometimes entertained concerning the quantity of matter in our sky. Suppose a shell to surround the earth at a height above the surface which would place it beyond the grosser matter that hangs in the lower regions of the air—say at the height of the Matterhorn or Mont Blanc. Outside this shell we have the deep blue firmament. Let the atmospheric space beyond the shell be swept clean, and let the sky-matter be properly gathered up. What is its probable amount? I have sometimes thought that a lady's portmanteau would contain it all. I have thought that even a gentleman's portmanteau—possibly his snuff-box—might take it in. And whether the actual sky be capable of this amount of condensation or not, I entertain no doubt that a sky quite as vast as ours, and as good in appearance, could be formed from a quantity of matter which might be held in the hollow of the hand.

Small in mass, the vastness in point of number of the particles of our sky may be inferred from the continuity of its light. It is not in broken patches, nor at scattered

points that the heavenly azure is revealed. To the observer on the summit of Mont Blanc the blue is as uniform and coherent as if it formed the surface of the most close-grained solid. A marble dome would not exhibit a stricter continuity. And Mr. Glaisher will inform you that if our hypothetical shell were lifted to twice the height of Mont Blanc above the earth's surface, we should still have the azure overhead. Everywhere through the atmosphere those sky-particles are strewn. They fill the Alpine valleys, spreading like a delicate gauze in front of the slopes of pine. They sometimes so swathe the peaks with light as to abolish their definition. This year I have seen the Weisshorn thus dissolved in opalescent air. By proper instruments the glare thrown from the sky-particles against the retina may be quenched, and then the mountain which it obliterated starts into sudden definition. Its extinction in front of a dark mountain resembles exactly the withdrawal of a veil. It is the light then taking possession of the eye, and not the particles acting as opaque bodies, that interfere with the definition. By day this light quenches the stars; even by moonlight it is able to exclude from vision all stars between the fifth and the eleventh magnitude. It may be likened to a noise, and the stellar radiance to a whisper drowned by the noise. What is the nature of the particles which shed light? The celebrated De la Rive ascribes the haze of the Alps in fine weather to floating organic germs. Now the possible existence of germs in such profusion has been held up as an absurdity. It has been affirmed that they would darken the air, and on the assumed impossibility of their existence in the requisite numbers, without invasion of the solar light, a powerful argument has been based by believers in spontaneous generation. Similar arguments have been used by the opponents of the germ theory of

epidemic disease, and both parties have triumphantly challenged an appeal to the microscope and the chemist's balance to decide the question. Such arguments are absolutely valueless. Without committing myself in the least to De la Rive's notion, without offering any objection here to the doctrine of spontaneous generation, without expressing any adherence to the germ theory of disease, I would simply draw attention to the fact that in the atmosphere we have particles which defy both the microscope and the balance, which do not darken the air, and which exist, nevertheless, in multitudes sufficient to reduce to insignificance the Israelitish hyperbole regarding the sands upon the seashore.

The varying judgments of men on these and other questions may perhaps be, to some extent, accounted for by that doctrine of Relativity which plays so important a part in philosophy. This doctrine affirms that the impressions made upon us by any circumstance, or combination of circumstances, depends upon our previous state. Two travellers upon the same peak, the one having ascended to it from the plain, the other having descended to it from a higher elevation, will be differently affected by the scene around them. To the one nature is expanding, to the other it is contracting, and feelings are sure to differ which have two such different antecedent states. In our scientific judgments the law of relativity may also play an important part. To two men, one educated in the school of the senses, who has mainly occupied himself with observation, and the other educated in the school of imagination as well, and exercised in the conceptions of atoms and molecules to which we have so frequently referred, a bit of matter, say $\frac{1}{50000}$th of an inch in diameter, will present itself differently. The one descends to it from his molar heights, the other climbs to it from his molecular low-

lands. To the one it appears small, to the other large. So also as regards the appreciation of the most minute forms of life revealed by the microscope. To one of these men they naturally appear conterminous with the ultimate particles of matter, and he readily figures the molecules from which they directly spring; with him there is but a step from the atom to the organism. The other discerns numberless organic gradations between both. Compared with his atoms, the smallest vibrios and bacteria of the microscopic field are as behemoth and leviathan. The law of relativity may to some extent explain the different attitudes of these two men with regard to the question of spontaneous generation. An amount of evidence which satisfies the one entirely fails to satisfy the other; and while to the one the last bold defence and startling expansion of the doctrine will appear perfectly conclusive, to the other it will present itself as imposing a profitless labour of demolition on subsequent investigators.*

I trust, Mr. President, that you—whom untoward circumstances have made a biologist, but who still keep alive your sympathy with that class of enquiries which nature intended you to pursue and adorn—will excuse me to your brethren if I say that some of them seem to form an inade quate estimate of the distance which separates the microscopic from the molecular limit, and that, as a consequence, they sometimes employ a phraseology which is calculated to mislead. When, for example, the contents of a cell are described as perfectly homogeneous, as absolutely structureless, because the microscope fails to distinguish any structure, then I think the microscope begins to play a mischievous part. A little consideration will make it plain

* A resolute scrutiny of the experiments, recently executed with reference to this question, is sure to yield instructive results.

to all of you that the microscope can have no voice in the real question of germ structure. Distilled water is more perfectly homogeneous than the contents of any possible organic germ. What causes the liquid to cease contracting at 39° Fahr., and to grow bigger until it freezes? It is a structural process of which the microscope can take no note, nor is it likely to do so by any conceivable extension of its powers. Place this distilled water in the field of an electro-magnet, and bring a microscope to bear upon it. Will any change be observed when the magnet is excited? Absolutely none; and still, profound and complex changes have occurred. First of all, the particles of water are rendered diamagnetically polar; and secondly, in virtue of the structure impressed upon it by the magnetic strain of its molecules, the liquid twists a ray of light in a fashion perfectly determinate both as to quantity and direction. It would be immensely interesting to both you and me if one whom I hoped to see here present,* who has brought his brilliant imagination to bear upon this subject, could make us see as he sees the entangled molecular processes involved in the rotation of the plane of polarisation by magnetic force. While dealing with this question, he lived in a world of matter and of motion to which the microscope has no passport, and in which it can offer no aid. The cases in which similar conditions hold are simply numberless. Have the diamond, the amethyst, and the countless other crystals formed in the laboratories of nature and of man no structure? Assuredly they have; but what can the microscope make of it? Nothing. It cannot be too distinctly borne in mind that between the microscope limit and the true molecular limit there is room for infinite permutations and combinations. It is in this region that the poles of the atoms are arranged, that tendency is given

* Sir William Thomson.

to their powers, so that when these poles and powers have free action and proper stimulus in a suitable environment, they determine first the germ and afterwards the complete organism. This first marshalling of the atoms on which all subsequent action depends baffles a keener power than that of the microscope. Through pure excess of complexity, and long before observation can have any voice in the matter, the most highly trained intellect, the most refined and disciplined imagination, retires in bewilderment from the contemplation of the problem. We are struck dumb by an astonishment which no microscope can relieve, doubting not only the power of our instrument, but even whether we ourselves possess the intellectual elements which will ever enable us to grapple with the ultimate structural energies of nature.

But the speculative faculty, of which imagination forms so large a part, will nevertheless wander into regions where the hope of certainty would seem to be entirely shut out. We think that though the detailed analysis may be, and may ever remain, beyond us, general notions may be attainable. At all events, it is plain that beyond the present outposts of microscopic enquiry lies an immense field for the exercise of the speculative power. It is only, however, the privileged spirits who know how to use their liberty without abusing it, who are able to surround imagination by the firm frontiers of reason, that are likely to work with any profit here. But freedom to them is of such paramount importance that, for the sake of securing it, a good deal of wildness on the part of weaker brethren may be overlooked. In more senses than one Mr. Darwin has drawn heavily upon the scientific tolerance of his age. He has drawn heavily upon *time* in his development of species, and he has drawn adventurously upon *matter* in his theory of

pangenesis. According to this theory, a germ already microscopic is a world of minor germs. Not only is the organism as a whole wrapped up in the germ, but every organ of the organism has there its special seed. This, I say, is an adventurous draft on the power of matter to divide itself and distribute its forces. But, unless we are perfectly sure that he is overstepping the bounds of reason, that he is unwittingly sinning against observed fact or demonstrated law—for a mind like that of Darwin can never sin wittingly against either fact or law—we ought, I think, to be cautious in limiting his intellectual horizon. If there be the least doubt in the matter, it ought to be given in favour of the freedom of such a mind. To it a vast possibility is in itself a dynamic power, though the possibility may never be drawn upon. It gives me pleasure to think that the facts and reasonings of this discourse tend rather towards the justification of Mr. Darwin than towards his condemnation, that they tend rather to augment than to diminish the cubic space demanded by this soaring speculator; for they seem to show the perfect competence of matter and force, as regards divisibility and distribution, to bear the heaviest strain that he has hitherto imposed upon them.

In the case of Mr. Darwin, observation, imagination, and reason combined have run back with wonderful sagacity and success over a certain length of the line of biological succession. Guided by analogy, in his 'Origin of Species,' he placed at the root of life a primordial germ, from which he conceived the amazing richness and variety of the life that now is upon the earth's surface might be deduced. If this were true, it would not be final. The human imagination would infallibly look behind the germ, and enquire into the history of its genesis. Certainty is here hopeless, but the materials for an opinion may be attainable.

In this dim twilight of conjecture the enquirer welcomes every gleam, and seeks to augment his light by indirect incidences. He studies the methods of nature in the ages and the worlds within his reach, in order to shape the course of speculation in the antecedent ages and worlds. And though the certainty possessed by experimental enquiry is here shut out, the imagination is not left entirely without guidance. From the examination of the solar system, Kant and Laplace came to the conclusion that its various bodies once formed parts of the same undislocated mass; that matter in a nebulous form preceded matter in a dense form; that as the ages rolled away, heat was wasted, condensation followed, planets were detached, and that finally the chief portion of the fiery cloud reached, by self-compression, the magnitude and density of our sun. The earth itself offers evidence of a fiery origin; and in our day the hypothesis of Kant and Laplace receives the independent countenance of spectrum analysis, which proves the same substances to be common to the earth and sun. Accepting some such view of the construction of our system as probable, a desire immediately arises to connect the present life of our planet with the past. We wish to know something of our remotest ancestry. On its first detachment from the central mass, life, as we understand it, could hardly have been present on the earth. How then did it come there? The thing to be encouraged here is a reverent freedom—a freedom preceded by the hard discipline which checks licentiousness in speculation—while the thing to be repressed, both in science and out of it, is dogmatism. And here I am in the hands of the meeting—willing to end, but ready to go on. I have no right to intrude upon you, unasked, the unformed notions which are floating like clouds, or gathering to more solid consistency in the

modern speculative scientific mind. But if you wish me to speak plainly, honestly, and undisputatiously, I am willing to do so. On the present occasion—

> You are ordained to call, and I to come.

Two views, then, offer themselves to us. Life was present potentially in matter when in the nebulous form, and was unfolded from it by the way of natural development, or it is a principle inserted into matter at a later date. With regard to the question of time, the views of men have changed remarkably in our day and generation; and I must say as regards courage also, and a manful willingness to engage in open contest, with fair weapons, a great change has also occurred. The clergy of England—at all events the clergy of London—have nerve enough to listen to the strongest views which any one amongst us would care to utter; and they invite, if they do not challenge, men of the most decided opinions to state and stand by those opinions in open court. No theory upsets them. Let the most destructive hypothesis be stated only in the language current among gentlemen, and they look it in the face. They forego alike the thunders of heaven and the terrors of the other place, smiting the theory, if they do not like it, with honest secular strength. In fact, the greatest cowards of the present day are not to be found among the clergy, but within the pale of science itself.

Two or three years ago in an ancient London College—a clerical institution—I heard a very remarkable lecture by a very remarkable man. Three or four hundred clergymen were present at the lecture. The orator began with the civilisation of Egypt in the time of Joseph; pointing out that the very perfect organisation of the kingdom, and the possession of chariots, in one of which Joseph rode, indicated a long antecedent period of civilisation. He then

passed on to the mud of the Nile, its rate of augmentation, its present thickness, and the remains of human handywork found therein; thence to the rocks which bound the Nile valley, and which teem with organic remains. Thus in his own clear and admirable way he caused the idea of the world's age to expand itself indefinitely before the mind of his audience, and he contrasted this with the age usually assigned to the world. During his discourse he seemed to be swimming against a stream; he manifestly thought that he was opposing a general conviction. He expected resistance; so did I. But it was all a mistake: there was no adverse current, no opposing conviction, no resistance, merely here and there a half-humorous, but unsuccessful attempt to entangle him in his talk. The meeting agreed with all that had been said regarding the antiquity of the earth and of its life. They had, indeed, known it all long ago, and they good-humouredly rallied the lecturer for coming amongst them with so stale a story. It was quite plain that this large body of clergymen, who were, I should say, the finest samples of their class, had entirely given up the ancient landmarks, and transported the conception of life's origin to an indefinitely distant past.

This leads us to the gist of our present enquiry, which is this:—Does life belong to what we call matter, or is it an independent principle inserted into matter at some suitable epoch—say when the physical conditions became such as to permit of the development of life? Let us put the question with all the reverence due to a faith and culture in which we all were cradled—a faith and culture, moreover, which are the undeniable historic antecedents of our present enlightenment. I say, let us put the question reverently, but let us also put it clearly and definitely. There are

the strongest grounds for believing that during a certain period of its history the earth was not, nor was it fit to be, the theatre of life. Whether this was ever a nebulous period, or merely a molten period, does not much matter; and if we revert to the nebulous condition, it is because the probabilities are really on its side. Our question is this:—Did creative energy pause until the nebulous matter had condensed, until the earth had been detached, until the solar fire had so far withdrawn from the earth's vicinity as to permit a crust to gather round the planet? Did it wait until the air was isolated, until the seas were formed, until evaporation, condensation, and the descent of rain had begun, until the eroding forces of the atmosphere had weathered and decomposed the molten rocks so as to form soils, until the sun's rays had become so tempered by distance and by waste as to be chemically fit for the decompositions necessary to vegetable life? Having waited through those Æons until the proper conditions had set in, did it send the fiat forth, 'Let Life be!'? These questions define a hypothesis not without its difficulties, but the dignity of which was demonstrated by the nobleness of the men whom it sustained.

Modern scientific thought is called upon to decide between this hypothesis and another: and public thought generally will afterwards be called upon to do the same. You may, however, rest secure in the belief that the hypothesis just sketched can never be stormed, and that it is sure, if it yield at all, to yield to a prolonged siege. To gain new territory modern argument requires more time than modern arms, though both of them move with greater rapidity than of yore. But however the convictions of individuals here and there may be influenced, the process must be slow and secular which com-

mends the rival hypothesis of Natural Evolution to the public mind. For what are the core and essence of this hypothesis? Strip it naked and you stand face to face with the notion that not alone the more ignoble forms of animalcular or animal life, not alone the nobler forms of the horse and lion, not alone the exquisite and wonderful mechanism of the human body, but that the human mind itself—emotion, intellect, will, and all their phenomena—were once latent in a fiery cloud. Surely the mere statement of such a notion is more than a refutation. But the hypothesis would probably go even further than this. Many who hold it would probably assent to the position that at the present moment all our philosophy, all our poetry, all our science, and all our art—Plato, Shakspeare, Newton, and Raphael—are potential in the fires of the sun. We long to learn something of our origin. If the Evolution hypothesis be correct, even this unsatisfied yearning must have come to us across the ages which separate the unconscious primeval mist from the consciousness of to-day. I do not think that any holder of the Evolution hypothesis would say that I overstate it or overstrain it in any way. I merely strip it of all vagueness, and bring before you unclothed and unvarnished the notions by which it must stand or fall.

Surely these notions represent an absurdity too monstrous to be entertained by any sane mind. Let us, however, give them fair play. Let us steady ourselves in front of the hypothesis, and, dismissing all terror and excitement from our minds, let us look firmly into it with the hard sharp eye of intellect alone. Why are these notions absurd, and why should sanity reject them? The law of Relativity, of which we have previously spoken, may find its application here. These Evolution notions are absurd, monstrous, and fit only for the intellectual

gibbet in relation to the ideas concerning matter which were drilled into us when young. Spirit and matter have ever been presented to us in the rudest contrast, the one as all-noble, the other as all-vile. But is this correct? Does it represent what our mightiest spiritual teacher would call the Eternal Fact of the Universe? Upon the answer to this question all depends. Supposing, instead of having the foregoing antithesis of spirit and matter presented to our youthful minds, we had been taught to regard them as equally worthy and equally wonderful; to consider them in fact as two opposite faces of the self-same mystery. Supposing that in youth we had been impregnated with the notion of the poet Goethe, instead of the notion of the poet Young, looking at matter, not as brute matter, but as 'the living garment of God;' do you not think that under these altered circumstances the law of Relativity might have had an outcome different from its present one? Is it not probable that our repugnance to the idea of primeval union between spirit and matter might be considerably abated? Without this total revolution of the notions now prevalent, the Evolution hypothesis must stand condemned; but in many profoundly thoughtful minds such a revolution has already taken place. They degrade neither member of the mysterious duality referred to; but they exalt one of them from its abasement, and repeal the divorce hitherto existing between both. In substance, if not in words, their position as regards the relation of spirit and matter is: 'What God hath joined together let not man put asunder.' And with regard to the ages of forgetfulness which lie between the unconscious life of the nebula and the conscious life of the earth, it is, they would urge, but an extension of that forgetfulness which preceded the birth of us all.

I have thus led you to the outer rim of speculative science, for beyond the nebulæ scientific thought has never ventured hitherto, and have tried to state that which I considered ought, in fairness, to be outspoken. I do not think this Evolution hypothesis is to be flouted away contemptuously; I do not think it is to be denounced as wicked. It is to be brought before the bar of disciplined reason, and there justified or condemned. Let us hearken to those who wisely support it, and to those who wisely oppose it; and let us tolerate those, and they are many, who foolishly try to do either of these things.* The only thing out of place in the discussion is dogmatism on either side. Fear not the Evolution hypothesis. Steady yourselves in its presence upon that faith in the ultimate triumph of truth which was expressed by old Gamaliel when he said:—'If it be of God, ye cannot overthrow it; if it be of man, it will come to nought.' Under the fierce light of scientific enquiry, this hypothesis is sure to be dissipated if it possess not a core of truth. Trust me, its existence as a hypothesis in the mind is quite compatible with the simultaneous existence of all those virtues to which the term Christian has been applied. It does not solve—it does not profess to solve—the ultimate mystery of this universe. It leaves in fact that mystery untouched. For granting the nebula and its potential life, the question, whence came they? would still remain to baffle and bewilder us. At bottom, the hypothesis does nothing more than 'transport the conception of life's origin to an indefinitely distant past.'

* In the 'Prefatory Letter' to his 'Lay Sermons,' Mr. Huxley speaks of 'microscopists, ignorant alike of Philosophy and Biology.' With reference to one conspicuous member of this class, a doctor of medicine, lately professor in a London college famous for its orthodoxy, both Mr. Huxley and myself have long practised, and shall, I trust, continue to practise, the tolerance recommended above.

Those who hold the doctrine of Evolution are by no means ignorant of the uncertainty of their data, and they yield no more to it than a provisional assent. They regard the nebular hypothesis as probable, and in the utter absence of any evidence to prove the act illegal, they extend the method of nature from the present into the past. Here the observed uniformity of nature is their only guide. Within the long range of physical enquiry, they have never discerned in nature the insertion of caprice. Throughout this range the laws of physical and intellectual continuity have run side by side. Having thus determined the elements of their curve in a world of observation and experiment, they prolong that curve into an antecedent world, and accept as probable the unbroken sequence of development from the nebula to the present time. You never hear the really philosophical defenders of the doctrine of Uniformity speaking of *impossibilities* in nature. They never say, what they are constantly charged with saying, that it is impossible for the Builder of the universe to alter His work. Their business is not with the possible, but the actual—not with a world which *might* be, but with a world that *is*. This they explore with a courage not unmixed with reverence, and according to methods which, like the quality of a tree, are tested by their fruits. They have but one desire—to know the truth. They have but one fear—to believe a lie. And if they know the strength of science, and rely upon it with unswerving trust, they also know the limits beyond which science ceases to be strong. They best know that questions offer themselves to thought which science, as now prosecuted, has not even the tendency to solve. They keep such questions open, and will not tolerate any unlawful limitation of the horizon of their souls. They have as little fellowship with the atheist who says there is no God, as with the theist who

professes to know the mind of God. 'Two things,' said Immanuel Kant, 'fill me with awe: the starry heavens and the sense of moral responsibility in man.' And in his hours of health and strength and sanity, when the stroke of action has ceased and the pause of reflection has set in, the scientific investigator finds himself overshadowed by the same awe. Breaking contact with the hampering details of earth, it associates him with a power which gives fulness and tone to his existence, but which he can neither analyse nor comprehend.

SCIENTIFIC LIMIT OF THE IMAGINATION.*

The celebrated Fichte, in his lectures on the 'Vocation of the Scholar,' insisted on a culture for the scholar which should not be one-sided, but all-sided. His intellectual nature was to expand spherically and not in a single direction. In one direction, however, Fichte required that the scholar should apply himself directly to nature, become a creator of knowledge, and thus repay by original labours of his own the immense debt he owed to the labours of others. It was these which enabled him to supplement the knowledge derived from his own researches, so as to render his culture rounded and not one-sided.

As regards science Fichte's idea is to some extent illustrated by the constitution and the labours of the British Association. We have here a body of men engaged in the pursuit of Natural Knowledge, but variously engaged. While sympathizing with each of its departments, and supplementing his culture by knowledge drawn from all of them, each student amongst us selects one subject for the exercise of his own original faculty—one line along which he may carry the light of

* An Address to the Mathematical and Physical Section of the British Association assembled at Norwich on August 19, 1868.

his private intelligence a little way into the darkness by which all knowledge is surrounded. Thus, the geologist deals with the rocks; the biologist with the conditions and phenomena of life; the astronomer with stellar masses and motions; the mathematician with the relations of space and number; the chemist pursues his atoms, while the physical investigator has his own large field in optical, thermal, electrical, acoustical, and other phenomena. The British Association then, as a whole, faces physical nature on all sides and pushes knowledge centrifugally outwards, the sum of its labours constituting what Fichte might call the *sphere* of natural knowledge. In the meetings of the Association it is found necessary to resolve this sphere into its component parts, which take concrete form under the respective letters of our Sections.

This is the Mathematical and Physical Section. Mathematics and physics have been long accustomed to coalesce. For, no matter how subtle a natural phenomenon may be, whether we observe it in the region of sense, or follow it into that of imagination, it is in the long run reducible to mechanical laws. But the mechanical data once guessed or given, mathematics become all powerful as an instrument of deduction. The command of geometry over the relations of space, the far-reaching power which organised symbolic reasoning confers, are potent both as means of physical discovery, and of reaping the entire fruits of discovery. Indeed, without mathematics, expressed or implied, our knowledge of physical science would be friable in the extreme.

Side by side with the mathematical method we have the method of experiment. Here, from a starting-point furnished by his own researches or those of others, the investigator proceeds by combining intuition and verification. He ponders the knowledge he possesses

and tries to push it further, he guesses and checks his guess, he conjectures and confirms or explodes his conjecture. These guesses and conjectures are by no means leaps in the dark; for knowledge once gained casts a faint light beyond its own immediate boundaries. There is no discovery so limited as not to illuminate something beyond itself. The force of intellectual penetration into this penumbral region which surrounds actual knowledge is not, as some seem to think, dependent upon method, but upon the genius of the investigator. There is, however, no genius so gifted as not to need control and verification. The profoundest minds know best that Nature's ways are not at all times their ways, and that the brightest flashes in the world of thought are incomplete until they have been proved to have their counterparts in the world of fact. Thus the vocation of the true experimentalist may be defined as the continued exercise of spiritual insight, and its incessant correction and realization. His experiments constitute a body, of which his purified intuitions are, as it were, the soul.

Partly through mathematical and partly through experimental research, physical science has of late years assumed a momentous position in the world. Both in a material and in an intellectual point of view it has produced, and it is destined to produce, immense changes,—vast social ameliorations, and vast alterations in the popular conception of the origin, rule, and governance of natural things. By science, in the physical world, miracles are wrought, while philosophy is forsaking its ancient metaphysical channels and pursuing others which have been opened or indicated by scientific research. This must become more and more the case as philosophic writers become more deeply imbued with the methods of science, better acquainted with the facts which scientific

men have won, and with the great theories which they have elaborated.

If you look at the face of a watch, you see the hour- and minute-hands, and possibly also a second-hand, moving over the graduated dial. Why do these hands move? and why are their relative motions such as they are observed to be? These questions cannot be answered without opening the watch, mastering its various parts, and ascertaining their relationship to each other. When this is done, we find that the observed motion of the hands follows of necessity from the inner mechanism of the watch, when acted upon by the force invested in the spring.

The motion of the hands may be called a phenomenon of art, but the case is similar with the phenomena of nature. These also have their inner mechanism, and their store of force to set that mechanism going. The ultimate problem of physical science is to reveal this mechanism, to discern this store, and to show that from the combined action of both the phenomena of which they constitute the basis must of necessity flow.

I thought that an attempt to give you even a brief and sketchy illustration of the manner in which scientific thinkers regard this problem would not be uninteresting to you on the present occasion; more especially as it will give me occasion to say a word or two on the tendencies and limits of modern science; to point out the region which men of science claim as their own, and where it is mere waste of time to oppose their advance, and also to define, if possible, the bourne between this and that other region to which the questionings and yearnings of the scientific intellect are directed in vain.

But here your tolerance will be needed. It was the American Emerson, I think, who said that it is hardly

possible to state any truth strongly without apparent injustice to some other truth. Truth is often of a dual character, taking the form of a magnet with two poles; and many of the differences which agitate the thinking part of mankind are to be traced to the exclusiveness with which partisan reasoners dwell upon one half of the duality in forgetfulness of the other half. The proper course appears to be to state both halves strongly, and allow each its fair share in the formation of the resultant conviction. But this waiting for the statement of the two sides of a question implies patience. It implies a resolution to suppress indignation if the statement of the one half should clash with our convictions, and to repress equally undue elation if the half-statement should happen to chime in with our views. It implies a determination to wait calmly for the statement of the whole, before we pronounce judgment in the form of either acquiescence or dissent.

This premised, and, I trust, accepted, let us enter upon our task. There have been writers who affirmed that the pyramids of Egypt were the productions of nature; and in his early youth Alexander von Humboldt wrote a learned essay with the express object of refuting this notion. We now regard the pyramids as the work of men's hands, aided probably by machinery of which no record remains. We picture to ourselves the swarming workers toiling at those vast erections, lifting the inert stones, and, guided by the volition, the skill, and possibly at times by the whip of the architect, placing them in their proper positions. The blocks in this case were moved and posited by a power external to themselves, and the final form of the pyramid expressed the thought of its human builder.

Let us pass from this illustration of constructive power

to another of a different kind. When a solution of common salt is slowly evaporated, the water which holds the salt in solution disappears, but the salt itself remains behind. At a certain stage of concentration the salt can no longer retain the liquid form ; its particles, or molecules, as they are called, begin to deposit themselves as minute solids, so minute, indeed, as to defy all microscopic power. As evaporation continues solidification goes on, and we finally obtain, through the clustering together of innumerable molecules, a finite crystalline mass of a definite form. What is this form ? It sometimes seems a mimicry of the architecture of Egypt. We have little pyramids built by the salt, terrace above terrace from base to apex, forming a series of steps resembling those up which the Egyptian traveller is dragged by his guides. The human mind is as little disposed to look unquestioning at these pyramidal salt-crystals as to look at the pyramids of Egypt without inquiring whence they came. How, then, are those salt-pyramids built up ?

Guided by analogy, you may, if you like, suppose that, swarming among the constituent molecules of the salt, there is an invisible population, guided and coerced by some invisible master, and placing the atomic blocks in their positions. This, however, is not the scientific idea, nor do I think your good sense will accept it as a likely one. The scientific idea is that the molecules act upon each other without the intervention of slave labour ; that they attract each other and repel each other at certain definite points, or poles, and in certain definite directions ; and that the pyramidal form is the result of this play of attraction and repulsion. While, then, the blocks of Egypt were laid down by a power external to themselves, these molecular blocks of salt are self-posited, being fixed

in their places by the forces with which they act upon each other.

I take common salt as an illustration because it is so familiar to us all; but any other crystalline substance would answer my purpose equally well. Everywhere, in fact, throughout inorganic nature, we have this formative power, as Fichte would call it—this structural energy ready to come into play, and build the ultimate particles of matter into definite shapes. The ice of our winters and of our polar regions is its handywork, and so equally are the quartz, felspar, and mica of our rocks. Our chalk-beds are for the most part composed of minute shells, which are also the product of structural energy; but behind the shell, as a whole, lies a more remote and subtle formative act. These shells are built up of little crystals of calc-spar, and to form these crystals the structural force had to deal with the intangible molecules of carbonate of lime. This tendency on the part of matter to organize itself, to grow into shape, to assume definite forms in obedience to the definite action of force, is, as I have said, all-pervading. It is in the ground on which you tread, in the water you drink, in the air you breathe. Incipient life, as it were, manifests itself throughout the whole of what we call inorganic nature.

The forms of the minerals resulting from this play of polar forces are various, and exhibit different degrees of complexity. Men of science avail themselves of all possible means of exploring their molecular architecture. For this purpose they employ in turn as agents of exploration, light, heat, magnetism, electricity, and sound. Polarized light is especially useful and powerful here. A beam of such light, when sent in among the molecules of a crystal, is acted on by them, and from this action we infer with more or less of clearness the manner in which

the molecules are arranged. That differences, for example, exist between the inner structure of rock salt and crystallized sugar or sugar-candy, is thus strikingly revealed. These differences may be made to display themselves in chromatic phenomena of great splendour, the play of molecular force being so regulated as to remove some of the coloured constituents of white light, and to leave others with increased intensity behind.

And now let us pass from what we are accustomed to regard as a dead mineral to a living grain of corn. When *it* is examined by polarized light, chromatic phenomena similar to those noticed in crystals are observed. And why? Because the architecture of the grain resembles the architecture of the crystal. In the grain also the molecules are set in definite positions, and in accordance with their arrangement they act upon the light. But what has built together the molecules of the corn? I have already said regarding crystalline architecture that you may, if you please, consider the atoms and molecules to be placed in position by a power external to themselves. The same hypothesis is open to you now. But if in the case of crystals you have rejected this notion of an external architect, I think you are bound to reject it now, and to conclude that the molecules of the corn are self-posited by the forces with which they act upon each other. It would be poor philosophy to invoke an external agent in the one case and to reject it in the other.

Instead of cutting our grain of corn into slices and subjecting it to the action of polarized light, let us place it in the earth and subject it to a certain degree of warmth. In other words, let the molecules, both of the corn and of the surrounding earth, be kept in that state of agitation which we call warmth. Under these circumstances, the grain and the substances which surround it interact, and

a definite molecular architecture is the result. A bud is formed; this bud reaches the surface, where it is exposed to the sun's rays, which are also to be regarded as a kind of vibratory motion. And as the motion of common heat with which the grain and the substances surrounding it were first endowed, enabled the grain and these substances to exercise their attractions and repulsions, and thus to coalesce in definite forms, so the specific motion of the sun's rays now enables the green bud to feed upon the carbonic acid and the aqueous vapour of the air. The bud appropriates those constituents of both for which it has an elective attraction, and permits the other constituent to resume its place in the air. Thus the architecture is carried on. Forces are active at the root, forces are active in the blade, the matter of the earth and the matter of the atmosphere are drawn towards both, and the plant augments in size. We have in succession the bud, the stalk, the ear, the full corn in the ear; the cycle of molecular action being completed by the production of grains similar to that with which the process began.

Now there is nothing in this process which necessarily eludes the conceptive or imagining power of the purely human mind. An intellect the same in kind as our own would, if only sufficiently expanded, be able to follow the whole process from beginning to end. It would see every molecule placed in its position by the specific attractions and repulsions exerted between it and other molecules, the whole process and its consummation being an instance of the play of molecular force. Given the grain and its environment, the purely human intellect might, if sufficiently expanded, trace out *à priori* every step of the process of growth, and by the application of purely mechanical principles demonstrate that the cycle must end, as it is seen to end, in the reproduction of forms like that

with which it began. A similar necessity rules here to that which rules the planets in their circuits round the sun.

You will notice that I am stating my truth strongly, as at the beginning we agreed it should be stated. But I must go still further, and affirm that in the eye of science *the animal body* is just as much the product of molecular force as the stalk and ear of corn, or as the crystal of salt or sugar. Many of the parts of the body are obviously mechanical. Take the human heart, for example, with its system of valves, or take the exquisite mechanism of the eye or hand. Animal heat, moreover, is the same in kind as the heat of a fire, being produced by the same chemical process. Animal motion, too, is as directly derived from the food of the animal, as the motion of Trevethyck's walking-engine from the fuel in its furnace. As regards matter, the animal body creates nothing; as regards force, it creates nothing. Which of you by taking thought can add one cubit to his stature? All that has been said, then, regarding the plant may be restated with regard to the animal. Every particle that enters into the composition of a muscle, a nerve, or a bone, has been placed in its position by molecular force. And unless the existence of law in these matters be denied, and the element of caprice introduced, we must conclude that, given the relation of any molecule of the body to its environment, its position in the body might be determined mathematically. Our difficulty is not with the *quality* of the problem, but with its *complexity*; and this difficulty might be met by the simple expansion of the faculties which we now possess. Given this expansion, with the necessary molecular data, and the chick might be deduced as rigorously and as logically from the egg as the existence of Neptune was deduced from the disturbances of Uranus, or as conical refraction was deduced from the undulatory theory of light.

You see I am not mincing matters, but avowing nakedly what many scientific thinkers more or less distinctly believe. The formation of a crystal, a plant, or an animal, is in their eyes a purely mechanical problem, which differs from the problems of ordinary mechanics in the smallness of the masses and the complexity of the processes involved. Here you have one half of our dual truth; let us now glance at the other half. Associated with this wonderful mechanism of the animal body we have phenomena no less certain than those of physics, but between which and the mechanism we discern no necessary connexion. A man, for example, can say *I feel*, *I think*, *I love*; but how does *consciousness* infuse itself into the problem? The human brain is said to be the organ of thought and feeling; when we are hurt the brain feels it, when we ponder it is the brain that thinks, when our passions or affections are excited it is through the instrumentality of the brain. Let us endeavour to be a little more precise here. I hardly imagine there exists a profound scientific thinker, who has reflected upon the subject, unwilling to admit the extreme probability of the hypothesis, that for every fact of consciousness, whether in the domain of sense, of thought, or of emotion, a certain definite molecular condition is set up in the brain; who does not hold this relation of physics to consciousness to be invariable, so that, given the state of the brain, the corresponding thought or feeling might be inferred; or given the thought or feeling, the corresponding state of the brain might be inferred.

But how inferred? It is at bottom not a case of logical inference at all, but of empirical association. You may reply that many of the inferences of science are of this character; the inference, for example, that an electric current of a given direction will deflect a mag-

netic needle in a definite way; but the cases differ in this, that the passage from the current to the needle, if not demonstrable, is thinkable, and that we entertain no doubt as to the final mechanical solution of the problem. But the passage from the physics of the brain to the corresponding facts of consciousness is unthinkable. Granted that a definite thought, and a definite molecular action in the brain occur simultaneously; we do not possess the intellectual organ, nor apparently any rudiment of the organ, which would enable us to pass, by a process of reasoning, from the one to the other. They appear together; but we do not know why. Were our minds and senses so expanded, strengthened, and illuminated as to enable us to see and feel the very molecules of the brain; were we capable of following all their motions, all their groupings, all their electric discharges, if such there be; and were we intimately acquainted with the corresponding states of thought and feeling, we should be as far as ever from the solution of the problem. 'How are these physical processes connected with the facts of consciousness?' The chasm between the two classes of phenomena would still remain intellectually impassable. Let the consciousness of *love*, for example, be associated with a right-handed spiral motion of the molecules of the brain, and the consciousness of *hate* with a left-handed spiral motion. We should then know when we love that the motion is in one direction, and when we hate that the motion is in the other; but the 'WHY?' would remain as unanswerable as before.

In affirming that the growth of the body is mechanical, and that thought, as exercised by us, has its correlative in the physics of the brain, I think the position of the 'Materialist' is stated, as far as that position is a tenable one. I think the materialist will be able finally to main-

tain this position against all attacks; but I do not think, in the present condition of the human mind, that he can pass beyond this position. I do not think he is entitled to say that his molecular groupings and his molecular motions *explain* everything. In reality they explain nothing. The utmost he can affirm is the association of two classes of phenomena, of whose real bond of union he is in absolute ignorance. The problem of the connexion of body and soul is as insoluble in its modern form as it was in the prescientific ages. Phosphorus is known to enter into the composition of the human brain, and a trenchant German writer has exclaimed, 'Ohne Phosphor, kein Gedanke.' That may or may not be the case; but even if we knew it to be the case, the knowledge would not lighten our darkness. On both sides of the zone here assigned to the materialist he is equally helpless. If you ask him whence is this 'Matter' of which we have been discoursing, who or what divided it into molecules, who or what impressed upon them this necessity of running into organic forms, he has no answer. Science is mute in reply to these questions. But if the materialist is confounded and science rendered dumb, who else is prepared with a solution? To whom has this arm of the Lord been revealed? Let us lower our heads and acknowledge our ignorance, priest and philosopher, one and all. Perhaps the mystery may resolve itself into knowledge at some future day. The process of things upon this earth has been one of amelioration. It is a long way from the Iguanodon and his contemporaries to the President and Members of the British Association. And whether we regard the improvement from the scientific or from the theological point of view, as the result of progressive development, or as the result of successive exhibitions of creative energy, neither view entitles us to

assume that man's present faculties end the series,—that the process of amelioration stops at him. A time may therefore come when this ultra-scientific region by which we are now enfolded may offer itself to terrestrial, if not to human investigation. Two-thirds of the rays emitted by the sun fail to arouse in the eye the sense of vision. The rays exist, but the visual organ requisite for their translation into light does not exist. And so from this region of darkness and mystery which surrounds us, rays may now be darting which require but the development of the proper intellectual organs to translate them into knowledge as far surpassing ours as ours surpasses that of the wallowing reptiles which once held possession of this planet. Meanwhile the mystery is not without its uses. It certainly may be made a power in the human soul; but it is a power which has feeling, not knowledge, for its base. It may be, and will be, and we hope is turned to account, both in steadying and strengthening the intellect, and in rescuing man from that littleness to which, in the struggle for existence, or for precedence in the world, he is continually prone.

EARLIER THOUGHTS.*

A WORK recently published by Mr. Murray contains a sketch of the grounds on which the most advanced scientific thinkers of the present day base their convictions as to the physical character of Light and Heat. The fundamental idea there developed is, that the phenomena of light and heat, like those of sound, are essentially *mechanical.* Precisely the same reasoning applies to the vibrating ether which produces the one as to the vibrating air which produces the other, and both are dealt with substantially as we should deal with the waves of a liquid or the swing of a pendulum. Reflection on this subject has suggested the thought that the considerations brought forward in the sketch referred to may apply themselves to certain phenomena which are usually considered to lie outside the pale of physics, and thus may indicate new relationships between man regarded as a being of intellect and emotion, and the wondrous material system in the midst of which he dwells.

All our intercourse with the external world consists exclusively in an interchange of motion. From a vibrating, sonorous body, for example, pulses are sent to the ear and stir the auditory nerve to motion. From a luminous body pulses are sent to the eye, and stir the optic nerve to motion. Other pulses of different periods strike

* From an article headed 'Physics and Metaphysics,' in the *Saturday Review* for August 4, 1860.

upon other nerves, and produce the sensation of heat; but, in all cases, whether it be light, or sound, or ordinary feeling, the excitement of the nerves, regarded more strictly, is the excitement of motion. And if the motion be induced by internal causes instead of external, is it not fair to infer that the effect on consciousness will be the same? Let any nerve, for example, be thrown by morbid action into the precise state of motion which would be communicated to it by the pulses of a heated body, surely that nerve will declare itself hot—the mind will accept the subjective intimation exactly as if it were objective. The retina, as is well known, may be excited by purely mechanical means. A blow on the eye will cause a luminous flash, and the mere pressure of the finger on the external ball will produce a star of light, which Newton compared to the circles on a peacock's tail. Disease makes people see visions and dream dreams; but, in all such cases, could we examine the organs implicated, we should, on philosophical grounds, expect to find them in that precise molecular condition which the real objects, if present, would superinduce.

The colour of light is determined by the frequency of the ethereal vibrations, as the pitch of sound is determined by the frequency of the aërial ones. The red or purple, for example, of a British maiden's cheek and lips, the blue, violet, or brown of her eyes, have their strict physical equivalents in the lengths of the waves which issue from them; and these waves are not only as truly mechanical as the waves of the sea, but they are capable of having their mechanical value expressed in numbers. In the work already referred to, a chapter is devoted to the relation which subsists between light and heat and mere mechanical work. In virtue of this relation we can tell the precise amount of work which a given amount of sunshine

can perform. Now, the hue of the cheek is caused by the extinction of certain of the solar rays by the colouring matter of the cheek, the residual colour being that seen. Could we interpose the substance to which some English cheeks owe their bloom in the path of a beam passing through a prism, we should probably find the orange and yellow and green of the prismatic spectrum more or less absorbed, the red and a portion of the blue being transmitted. This would give us a purplish blush resembling that of the permanganate of potash, commonly called the mineral chameleon, a solution of which acts upon the spectrum in the manner just described. Inasmuch, then, as we can calculate with perfect exactness the mechanical value of the total light which falls upon the epidermis, a certain fraction of this will express the mechanical value of the cheek's colour. We do not therefore jest, but speak the words of truth and soberness when we affirm that the rays to which the tinting of any given cheek is due would, if mechanically applied, be competent to move a wheelbarrow through a certain space, or to lift a scuttle of coals to a certain calculable elevation.

But the human face and eyes flush at times with a radiance which might well be taken for a direct spiritual emanation entirely independent of 'brute matter.' Let us examine this point a little. Musical instruments, and also the human voice, have a peculiarity as regards their sounds which differs from mere pitch. A clarionet and a violin, for example, may be both pitched to the same note, but a listener who sees neither can at once tell that the *qualities* of the notes are different. This difference is what the French call *timbre*, and the Germans, we believe, *Klang*. So, also, we can distinguish one vowel from another, though all may have the same

pitch. The difference here, according to the recent investigations of Helmholtz, is due to the fact that certain incidental notes commingle in each case with the principal one, and produce a composite result. The 'harmonics' of a string are known to be due to minor vibrations which superpose themselves upon the principal ones, as small ripples cover parasitically the surfaces of large sea-waves. The notes of the true simple wave and of its parasites are heard at once, and it is the variation of the latter which produces differences in the *timbre* of a musical instrument or of the human voice.

In speculating on those more subtle phases of expression to which we have above referred, might we not offer the conjecture that they are not due to those waves alone which make the eyes violet or give the cheek its rose, but are a result produced by the compounding of these with incidental waves, which influence the colour as the harmonic waves of sound influence the pure quality of a note? We have often watched with deep interest and sympathy the countenances of some of the praying women in the churches of the Continent. We have seen a penitent kneeling at a distance from the shrine of the Virgin, as if afraid to come nearer. Suddenly a glow has overspread her countenance, strengthening in radiance, till at length her very soul seemed shining through her features. Sure of her acceptance, she has confidently advanced, fallen prostrate immediately in front of the image, and remained there for a time in silent ecstasy. We have watched the ebbing of the spiritual tide, and remarked the felicitous repose which it left behind. At each new phase of emotion the *timbre* of this woman's countenance changed, and

> The music breathing from her face

became altered in quality.

The tendency of the above remarks is to show that the most subtle phases of 'expression' have at least a proximate mechanical origin. The splendours of the 'imperial Eleänore'—the 'languors of her love deep eyes'—are all reducible to the same cause; and not only so, but they actually exist for a time in space, isolated alike from her and her worshipper. Every gleam of those eyes, every flush of her brows, every motion of her lips requires the ether for its transmission, and a certain calculable time to pass from her to him. During this time, the expression which is to stir the soul, to kindle love or quench it, exists in space as a purely mechanical affection of matter; and, for aught we know, a slight steepness in the front of an ethereal billow, a slight curl of its crest, or some other accident of form, may determine whether the recipient of its shock is to be elated with joy or steeped in misery.

The philosophy of the future will assuredly take more account than that of the past of the relation of thought and feeling to physical processes; and it may be that the qualities of the mind will be studied through the organism as we now study the character of a force through the affections of ordinary matter. We believe that every thought and every feeling has its definite mechanical correlative—that it is accompanied by a certain separation and remarshalling of the atoms of the brain. This latter process is purely physical; and were the faculties we now possess sufficiently strengthened, without the creation of any new faculty, it would doubtless be within the range of our augmented powers to infer from the molecular state of the brain the character of the thought acting on it, and conversely to infer from the thought the exact molecular condition of the brain. We do not say—and this, as will be seen, is all-important—

that the inference here referred to would be an *à priori* one. But by observing, with the faculties we assume, the state of the brain and the associated mental affections, both might be so tabulated side by side that, if one were given, a mere reference to the table would declare the other. Our present powers, it is true, shrivel into nothingness when brought to bear on such a problem, but it is because of its complexity and our limits that this is the case. The *quality* of the problem and the *quality* of our powers are, we believe, so related, that a mere expansion of the latter would enable them to cope with the former. Why, then, in scientific speculation should we turn our eyes exclusively to the humble past? May it not be that a time is coming—ages no doubt distant, but still advancing—when the dwellers upon earth, starting from the gross human brain of to-day as a rudiment, may be able to apply to these mighty questions faculties of commensurate extent? Given the requisite expansibility to the present senses and intelligence of man—given also the time necessary for their expansion—and this high goal may be attained. Development is all that is required, and not a change of quality. There need be no absolute breach of continuity between us and our loftier brothers yet to come.

We have guarded ourselves against saying that the inferring of thought from material combinations and arrangements would be an inference *à priori*. The inference meant would be the same in kind as that which the observation of the effects of food and drink upon the mind would enable us to make, differing only from the latter in the degree of analytical insight which we suppose attained. Given the masses and distances of the planets, we can infer the perturbations consequent on their mutual attractions. Given the nature of a disturbance in water,

air, or ether—from the physical qualities of the medium we can infer how its particles will be affected. Here the mind runs with certainty along the line of thought which connects the phenomena, and from beginning to end finds no break in the chain. But when we endeavour to pass by a similar process from the phenomena of physics to those of thought, we meet a problem which transcends any conceivable expansion of the powers which we now possess. We may think over the subject again and again, but it eludes all intellectual presentation. We stand at length face to face with the Incomprehensible. The territory of physics is wide, but it has its limits from which we look with vacant gaze into the region beyond. Whence come we; whither go we? The question dies without an answer—without even an echo—upon the infinite shores of the Unknown. Let us follow matter to its utmost bounds; let us claim it in all its forms to experiment with and to speculate upon. Casting the term 'vital force' from our vocabulary, let us reduce, if we can, the visible phenomena of life to mechanical attractions and repulsions. Having thus exhausted physics, and reached its very rim, the real mystery still looms beyond us. We have, in fact, made no step towards its solution. And thus it will ever loom—ever beyond the bourne of knowledge—compelling the philosophies of successive ages to confess that

> ' We are such stuff
> As dreams are made of, and our little life
> Is rounded with a sleep.

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